Lecture 13: Tokens

CS 5430 3/16/2018

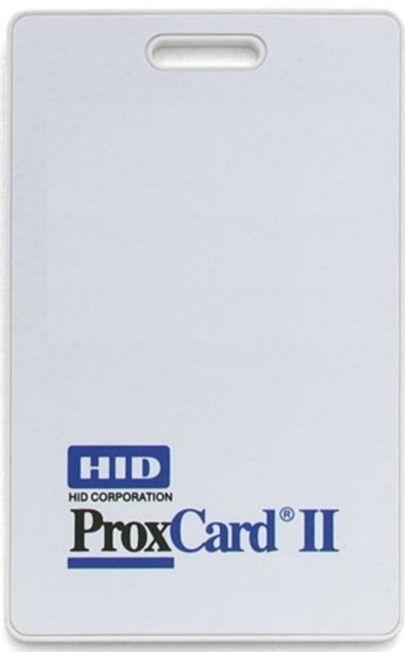
Review: Authentication of humans

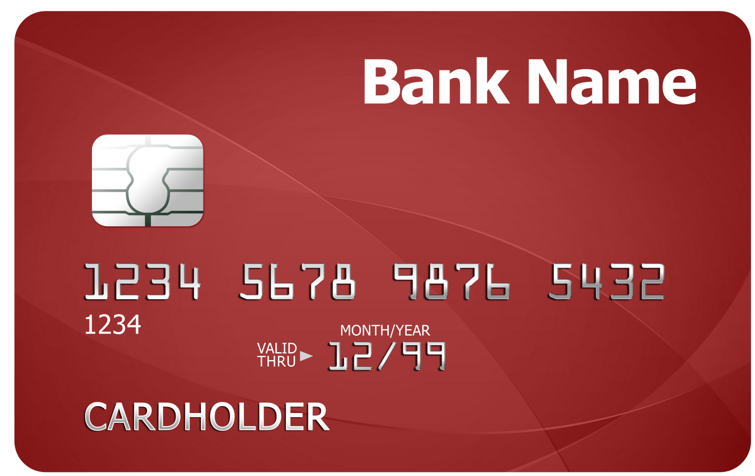
- Something you are
  fingerprint, retinal scan, hand silhouette, a pulse
- Something you know
  password, passphrase, PIN, answers to security questions
- Something you have
  physical key, ticket, {ATM, prox, credit} card, token

Humans vs. machines

- At enrollment, human is issued a token
  - Ranges from dumb (a physical key, a piece of paper) to a smart machine (a cryptographic processor)
  - Token becomes attribute of human's identity
- Authentication of human reduces to authentication of token

Authentication tokens





Threat Model: Eavesdropper

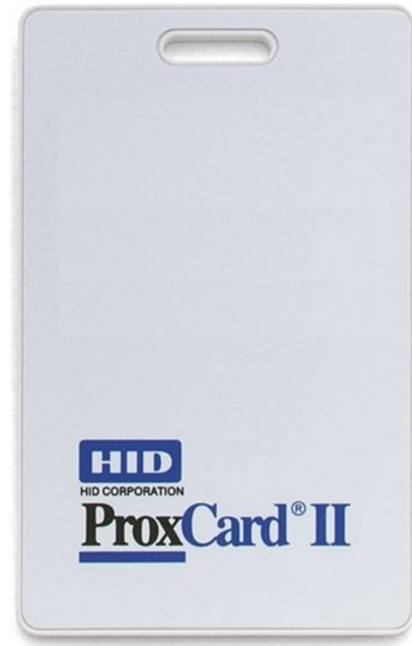
- Adversary can read read and replay messages
- Adversary cannot change messages during protocol execution (not full Dolev-Yao)

Fixed codes (Keyless Entry)

- Token stores a secret value id_T (e.g., key, id, password)
- Reader stores list of authorized ids
- To enter: `T->M: id_T`

- **Attack:** replay: thief sits in car nearby, records serial number, programs another token with same number, steals car
- **Attack:** brute force: serial numbers were 16 bits, devices could search through that space in under an hour for a single car (and in a whole parking lot, could unlock some car in under a minute)
- **Attack:** insider: serial numbers typically show up on many forms related to car, so mechanic, DMV, dealer's business office, etc. must be trusted

Fixed codes (RFIDs)



- Token stores a secret value id_T (e.g., key, id, password)
- Reader stores list of authorized ids
- To enter: `T->M: id_T`

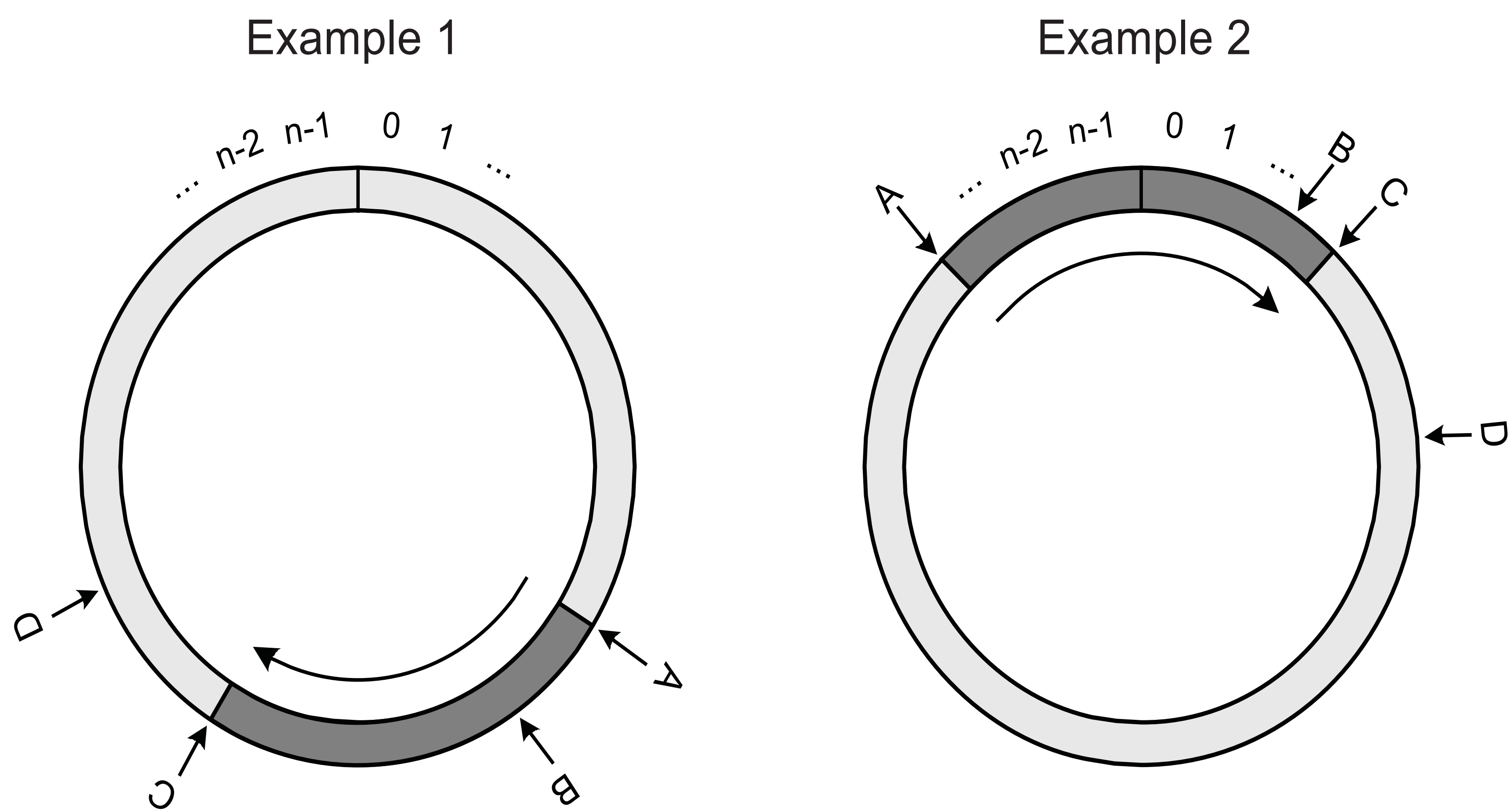
- **Attack:** replay: thief sits nearby, records serial number, programs another token with same number, authenticates
- **Attack:** privacy: adversary tracks token usage across system and learns user attributes and/or behaviors

- **Countermeasure:** one-time passwords

“Rolling” codes

- There is a master key, mk, for the barrier
- Token stores:
  - serial number T
  - nonce N, which is a sequence counter
  - shared key k, which is H(mk, T)
- Barrier stores:
  - all those values for all authorized tokens
  - as well as master key mk
- To enter: `T->B:  T, MAC(T, N; k)`
  - And T increments N
  - So does B if MAC tag verifies
- **Problem:** desynchronization of nonce
- **Partial solution:** accept “rolling window” of nonces

Rolling window



A - Value from last valid message

B - Accepted counter values

C - End of window

D - Rejected counter values

Image source: [Atmel]

One-Time Passwords

- OTP may be deemed valid only once (the first time)
- Adversary cannot predict future OTPs, even with complete knowledge of what passwords have already been used

One-time passwords

- A one-time password (OTP) is valid only once, the first time used
  - Similar to changing your password with every use
  - Rules out replays entirely
  - But man-in-the-middle could still succeed
- **Use case:** login at untrusted public machine where you fear keylogger
- **Use case:** recovery
  - "main password" is lost
  - phone is lost during two-factor authentication (e.g., Google backup codes)
- **Older use case:** send cleartext password over network

One-time passwords

- Strawman implementation: Pre-registered OTPs
- **Solution:** algorithmic generation of OTPs
  - SecureID can be seen as an instantiation: each code is a OTP valid for only 60 sec.
  - Iterated hashing is another possibility...

Unique challenge: MACs

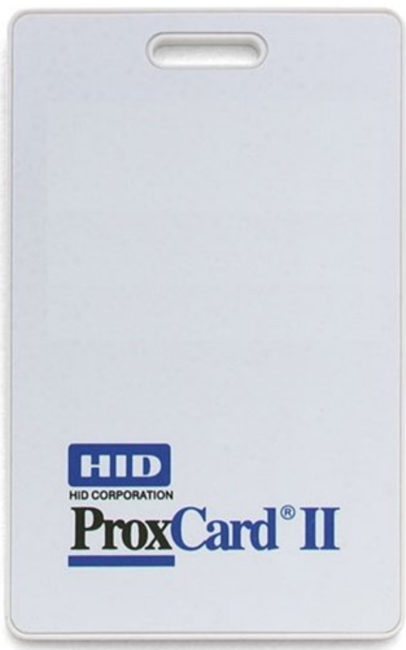
Assume: M stores a MAC key for each token,
i.e., a set of tuples (id_T, uid, k_T), and T stores k_T

```
1. U->M: I want to authenticate with T
2. M: invent unique nonce N
3. M->T: N
4. T: t=MAC(N; k_T)
5. T->M: id_T, t
6. M: lookup (uid, kT) for id_T;
      U is authenticated as uid if t=MAC(N; k_T)
```

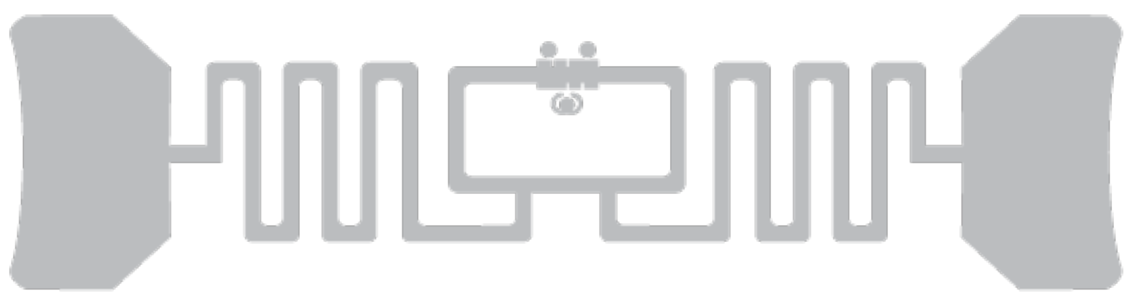
Non-problem: key distribution: already have to physically distribute tokens

Problem: key storage at L: what if key database is stolen?

EPC Gen2v2 RFID Cards



UCODE DNA



Unique challenge: Dig Sig

Assume: M stores a verification key for each token,
i.e., a set of tuples (id_T, uid, K_T), and T stores signing key k_T

```
1. U->M: I want to authenticate with T
2. M: invent unique nonce N
3. M->T: N
4. T: s=Sign(N; k_T)
5. T->M: id_T, s
6. M: lookup (uid, K_T) for id_T;
      U is authenticated as uid if Ver(N; s; K_T)
```

Quasi-problems: cost? performance? power? patents?

U2F

Two-factor with PIN

Assume: M also stores a PIN for each token, i.e., a set of tuples (id_T, uid, k_T, pin), and T stores k_T

```
1. U->M: I want to authenticate with T
2. M: invent unique nonce N
3. M->T: N
4. T->U: Enter PIN on my keyboard
5. U->T: pin
6. T: compute t=MAC(N, pin; k_T)
7. T->M: id_T, t
8. M: lookup (uid, pin, k_T) for id_T;
      U is authenticated as uid
        if t=MAC(N, pin); k_T)
```

Remote Authentication

- (Usually) No communication from server to token
- Usability considerations render challenge-response impractical

Hypothetical protocol

Assume: S stores a set of tuples (id_T, uid, kT, pin), and T stores kT

```
1. U->L: I want to authenticate as uid to S
2. L and S: establish secure channel
3. L->U: Enter PIN and code on my keyboard
4. T->U: code = MAC(time@T, id_T; kT)
5. U->L: pin, code
6. L: compute h = H(pin, code)
7. L->S: uid, h
8. S: lookup (pin, id_T, kT) for uid;
      id_Hu is authenticated
        if h=H(pin, MAC(time@S, id_T; kT))
```

Engineering challenge: clock synchronization

Estimating clock value

- Each device D has a clock C_D
  - model C_D as an non-decreasing, positive function of real time
- Server needs to estimate C_T(t_code): the time the token's clock displayed when the code was computed
- Clocks run at different rates and thus drift apart
  - we assume drift rate is bounded by a constant ρ
  - If $C\_T(t) = C\_S(t)$ then $|C\_T(t') – C\_S(t')| <= 2\rho(t'-t)$
- Messages take time d_min – d_max to deliver
- Clock estimation:
  - $C\_T(t\_prev) <= C\_T(t\_code)$
  - $C\_T(t\_code) \in [C\_S(t\_curr) + \Delta\_prev + d\_min - 2\rho(t\_curr - t\_prev),$
    $C\_S(t\_curr) + \Delta\_prev + d\_max + 2\rho(t\_curr - t\_prev)]$
  - To authenticate: check all possible times in range
  - On successful authentication, update t_prev

SecurID

- Token: displays code that changes every minute
  - LCD display
  - Internal clock (1 minute granularity)
  - No input channel
  - Can compute hashes, MACs
  - Stores a secret
- Ideas used:
  - replace nonce with current time
  - use L to input PIN
  - server checks $\pm$10 minutes to allow for clock drift

Paper “token”

```
...
~~50: MEND VOTE MALE HIRE BEAU LAY~~
~~49: PUG LYRA CANT JUDY BOAR AVON~~
48: LOAM OILY FISH CHAD BRIG NOV
47: RUE CLOG LEAK FRAU CURD SAM
46: COY LUG DORA NECK OILY HEAL
45: SUN GENE LOU HARD ELY HOG
44: GET CANE SOY NOR MATE DUEL
43: LUST TOUT NOV HAN BACH FADE
42: HOLM GIN MOLL JAY EARN BUFF
41: KEEN ABUT GALA ASIA DAM SINK
...
```

Hash chains

- Let $H^i(x)$ be i iterations of H applied to x
  - $H^0(x) = x$
  - $H^{i+1}(x) = H(H^i(x))$
- Hash chain: $H^1(x), H^2(x), H^3(x), \ldots, H^n(x)$

OTPs from hash chains

- Given a randomly chosen, large, secret seed s...
- **Bad idea:** generate a sequence of OTPs as a hash chain: $H^1(s)$, $H^2(s)$, ..., $H^n(s)$
  - Suppose untrusted public machine learns $H^i(s)$
  - From then on can compute next OTP $H^{i+1}(s)$ by applying H, because hashes are easy to compute in forward direction
  - But hashes are hard to invert...
- **Good idea [Lamport 1981]:** generate a sequence of OTPs as a reverse hash chain: $H^n(s)$, ..., $H^1(s)$
  - Suppose untrusted public machine learns $H^i(s)$
  - Next password is $H^{i-1}(s)$
  - Computing that is hard!

Protocol (almost)

Assume: S stores a set of tuples (uid, n_u, s_u)

```
1. U->L->S: uid
2. S: lookup (n_u, s_u) for uid;
      let n = n_u;
      let otp = H^n(s_u);
      decrement stored n_u
3. S->L->U: n
4. U: p = H^n(s_u)
5. U->L->S: p
6. S: uid is authenticated if p = otp
```

Problem: S has to compute a lot of hashes if authentication is frequent

Solution to S's hash burden

- S stores **`last`**: last successful OTP for id_Hu, where **`last`** = $H^{n+1}(s)$
- S receives **`next`**: next attempted OTP, where if all is well **`next`** = $H^n(s)$
- S checks its correctness with a single hash:

  H(**`next`**) = $H(H^n(s)) = H^{n+1}(s)$ = **`last`**
- And if correct S updates last successful OTP: **`last := next`**

Next problem: what if Hu and S don't agree on what password should be used next? i.e., become *desynchronized*

- network drops a message
- attacker does some online guessing (impersonating Hu) or spoofing (impersonating S)

Solution to desynchronization

- Hu and S independently store index of last used password from their own perspective, call them m_Hu and m_S
  - Neither is willing to reuse old passwords (i.e., higher indexes)
  - But both are willing to skip ahead to newer passwords (i.e., lower indexes)
- To authenticate:
  - S requests index m_S
  - Hu computes min(m_S, m_Hu), sends that along with OTP for it
  - S and Hu adjust their stored index

Next problem: running out of passwords: have to bother sysadmin to get new printed passwords periodically; might run out while traveling

Salted passwords as seed

- Compute OTP as H^n(pass,salt)
- Whenever Hu wants to generate new set of OTPs:
  - find a local machine Hu trusts (could be offline, phone, ...)
  - request new salt from S
  - enter pass
  - generate as many new OTPs as Hu likes by running hash forward
  - let S know how many were generated and what the last one was

Final protocol

Assume: S stores a set of tuples (uid, n_S, salt, last), Hu stores (pass, n_u)

```
1. U->L->S: uid
2. S: lookup n_S for uid
3. S->L->U: n_S
4. U: n = min(n_u, n_S) - 1;
        if n<=0 then abort
        else let p = H^n(pass, salt); // lookup on paper
             n_u := n  // cross off on paper
5. U->L->S: n, p
6. S: if n<n_S and H^(n_S-n)(p)=last
      then n_S := n;
           last := p;
           uid is authenticated
```

S/KEY

[RFC 1760]:

- Instantiation of that protocol for particular hash algorithms and sizes
- But same idea works for newer hashes and larger sizes

Solution to human computation

Problem: humans aren't good at typing long bit strings

Solution: represent bit strings as short words

i.e., divide hash output into chunks, use each chunk as index into dictionary, where each word in dictionary is fairly short

```
...
50: MEND VOTE MALE HIRE BEAU LAY
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```